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Application of Genetic Algorithms in the New Air Ttraffic Management Simulation System

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Abstract

The air traffic control systems are facing more and more serious congestions because of the increasing of air traffic flow in China. To solve the problem we have developed a New Air Traffic Management Simulation System that is according to the ideology of the New Air Traffic Management and the concept of Free Flight. First this paper analyses the mass design idea and the module functions, and then use the genetic algorithms to give the detail methods to solve the airline conflicts on airlines and aircraft sequence takeoff-landfall sorting schedule in the terminal airport area，at last we has achieved anticipative effect by use stimulant data compute in the system.

Keywords:air traffic simulation, air traffic control, genetic algorithm, temrinal area, dynamic queue

1.Introduction

With the rapid development of China's civil aviation and ever-growing air traffic flow in recent 10 years, and the expectable a large of private business aircrafts will be used in the near future, that will make the current air traffic control systems to be lapsed into unused. The increasing of air traffic flow in China makes the more and more serious aircraft conflicts, takeoff-landfall blocking and airspace congestions because the absence of the runway, airline and airspace. If air traffic controller can not solve the patient conflicts or can not arrange the airport traffic blocking rapidly, that will bring serious calamity and expensive lost.

New Air Traffic Management Simulation System (it will be called NATMSS on the next text) is an emulate system that has take the ideology of the New Air Traffic Management System and the concept of Free Flight, is to adapt the reform on air traffic management system and to catch the technical development foreland of the advanced country.

The Free Flight is one kind of flight mode that allows the pilot may choose the airline and flight speeds suitable for them. The obvious advantages are that can take the shortest fly distance, avoid the airline

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congestions, elevate the airspace utilize rate, reduce the fly time and cost, prevent the traffic delay. But in the meanwhile it leads to the hardly difficulties to detect the conflicts for the controllers. So we must to get a easy way to detect the aircraft conflicts ahead and to solve it in the least cost.

The New Air Traffic Management System has been approved by the International Civil Aviation Organization. The advanced country, for example USA, Russia, Australia etc, have been get great achievement after long time research, and they have launched the global satellite communication system as the base research and develop system, for GPG, GLONSS etc. Our country, China, already has possessed of such advanced system after twenty year's build of a large of base equipment, for instance, the satellite communication system, the radar detection system, air navigation system, computer network system of information etc. So we can establish the new kind of air traffic control system like as the New Air Traffic Management System.

2.The design and function analyse of the NATMSS

2.1.The design idea of the NATMSS

The research and development of the NATMSS is according to the idea of the New Air Traffic Management System, mainly to solve the problem of the super rapid developed and ever-growing air traffic flow in China. So we must use our scarcity air traffic resource more efficiently by means of to unify the cooperation, management and command. The purpose to build the NATMSS is to get a automatic network control system include airspace and ground control management by means of unify the several part data set as a integrative 4D track information data set, these part data set come from the satellite communication system, the ground navigation system and the airborne orientation system. For the purpose, use all the static scheduled flight plans as the calculate model to form a static air traffic management data set firstly, then to adjust or recomputed this new data set by paroxysmal event, such as the atrocious weather or the airport malfunction, and make sure that the adjustment has a least total cost.

2.2.The function analyse of the NATMSS

The NATMSS is composed of five function modules which are flight layout, terminal area control, airspace flow control, conflict detection and control, paroxysmal event manage. The function structure tree of this system is shown in below figure1.

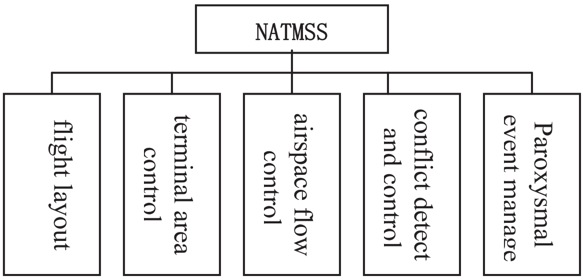

Figure1. systen function structure

The NATMSS relies on the flight layout subsystem to accomplish its responsibility. The flight layout subsystem is composed of two function parts: the static flight plans assignation function part and the dynamic flight plans adjustment function part. The function of part one is to accomplish the routine manage plans such as take-off and sit-down plans, fly route distribution, airspace surveillance etc, based on the flight plans that make out and approved in six months recently in our country. The function of another part is to adjust these manage plans that should be changed in the case caused by paroxysmal event, such as the atrocious weather or flight change requested suddenly, the concept of free flight is embodied on the case. The function of the terminal area control subsystem is the kernel function in the whole system, and is the bottleneck to determine business flow in the Civil Aviation. In this subsystem, we compute all the take-off and set-down limited flow of every terminal airport in the country as the base strategy to determine the max flow on each fly route way which belongs to some one airport to be controlled by the system, and then we can get the optimum efficiency by means of adopting the genetic algorithm to realize the automatic take-off and set-down sort manage plan. The function of the airspace flow control subsystem is to realize the optimum flow control by means of adopting multiple dynamic tasks network compute model based on the genetic algorithm. The function of the conflict detection and control subsystem is to detect conflicts of all flying flights and extricate these flights out of the dangerous state by using the satellite orientating function data and the flying report data and the radar surveillance data, to make sure all of the flying flights are safe. The function of the paroxysmal event manage subsystem is to handle the emergent events effectively and in time, these special events influence normal flights hardly take-off and set-down such as snowstorm. This paroxysmal event manage subsystem will restart the dynamic flight plans adjustment function part which is belonged to the flight layout subsystem to re-compute all the effected flight plans to solve the trouble only obey a rule that make sure has a least total cost for delay cost of all the adjusted flights.

In the mass, if this emulation system can be called a high efficiency system is determined by the function practicability of fly conflict detection, take-off and set-down control, fly route flow control.

3.The Fly conflict detection and extrication algorithm based on genetic algorithm

3.1.Genetic algorithm

Genetic Algorithm (be called GA on the next text) is a model method to construct an artificial system by mean of simulating the biology nature evolvement. It can solve the question with the property of application foreground, and adapts to construct every kind of complex forecast model which supports to get their answer data in the air traffic control realm. GA is a clustering method, and really is a senior algorithm for string search. It includes five basic factors, they are the parameter decode, race cluster initialization, adaptive functions design, inherited manipulation design, control parameters initialization and convergence functions design. On the other hand, GA has some disadvantages such as the shortcoming in solving the question about multi-levels, absence of dynamic changeability, hardly to get the complex spatial answers. So we must design the restricted conditions and replacement rules as perfect as possible, or integrate other effective algorithm when we use it.

3.2.The model and method for flight conflict detection

The current research about aircraft conflict detection and extrication is primarily of how to build the safe area model based on relative rules of fly alternation. We consider that the patient conflict will be produced when an aircraft goes into the protected safe area of another aircraft, and must handle the conflict at once. The safe area is designed as an ellipsoid that sketch map is showed in figure 2.

We set the aircraft's center of mass as the center point of the ellipsoid, use the horizontal alternation 's' as the semi-major axis, use the vertical alternation 'd' as the semi-minor axis. The projection of the ellipsoid is a circle on the surface of XOY with a radius equal to 10 kilo-meters, and the projection is an ellipse on the surface of XOZ and YOZ with a semi-major axis equal to 10 kilo-meters, and a semi-minor axis equal to 0.6 kilo-meters.

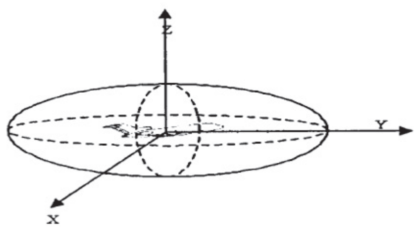

Figure2. safe area model of ellipsoid

If we define the position of the aircraft as the center point of coordinates system, thus the boundary of the ellipsoid can be denoted as expression as below:

$$\frac{x^2 + y^2}{s^2} + \frac{z^2}{d^2} = 1 \tag{1}$$

According to the aviation statute, we consider the conflict must be created and existed when the distance of any two aircrafts is less than the minimum safe alternation. If we designate the barycenter coordinates of the two aircrafts Ai and Aj as (xi， yi， zi) and (xj， yj， zi), then the vector of the relative position of the two aircrafts can be expressed as (△x， △y， △z), at last we can deduce the distance of the two aircrafts from their geometric relation, the result expression is showed below:

$$\sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \tag{2}$$

The length of the relative position of aircraft Ai in the safe area of aircraft Aj is expressed as below:

$$\sqrt{\frac{s^2 d^2 \cdot \left(\Delta x^2 + \Delta y^2 + \Delta z^2\right)}{s^2 \cdot \Delta z^2 + d^2 \cdot \left(\Delta x^2 + \Delta y^2\right)}} \tag{3}$$

The distance of the two aircrafts called rij can be expressed as below:：

$$r_{ij} = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} - \sqrt{\frac{s^2 d^2 \cdot \left(\Delta x^2 + \Delta y^2 + \Delta z^2\right)}{s^2 \cdot \Delta z^2 + d^2 \cdot \left(\Delta x^2 + \Delta y^2\right)}} \tag{4}$$

So the condition of the conflict produced in two aircrafts is： $r_{ij} \leqslant 0$.

3.3.The design of genetic algorithm for solving the fly conflict

The primary key to determine the performance of genetic algorithm is how to set the initial value to the two parameters of this algorithm which called the cross-probability (named Pc) and the aberrance-probability (named Pm). This operation affects the astringency of the algorithm. If the value of Pc is too big that will make the new individual gene to be created too fast, and will increase the possibility of destroying the genetic pattern. On the other hand, if the value of Pc is too small that will make the work of searching to became slow more and more, at last to be stopped. If the value of Pm is too small that will make the new individual gene to be created too slow. But if the value of Pm is too big that will make the genetic algorithm to be retrogressed to a common random searching algorithm. Thus, it is very difficult to get the optimal values of Pc and Pm to suit each problem.

Mr. Srinvivas and his colleagues bring forward a new self-adaptive genetic algorithm named AGA. The parameters Pc and Pm can automatic change following with the variety of adaptation in the new algorithm AGA. The detail operations of AGA are that to increase the values of Pc and Pm when all race cluster of genes become as same and get to local optimization, and to decrease the values of Pc and Pm when all race cluster of genes become dispersed. At the same time, set the lower values to the Pc and Pm for the individual gene which has the higher adaptive value than the average of whole race cluster of genes to make sure these genes go into the next generation, and set the higher values to the Pc and Pm for the individual gene which adaptive value is lower than the average level to make these genes to be eliminated. Thus AGA can provide the optimal results of Pc and Pm for some one problem, and can keep the astringency of the genetic algorithm when want to keep multiformity of the race cluster of genes. The values of Pc and Pm are set by according to the expressed as below when use the AGA to solve the problem of fly conflict:

$$P_c = \begin{cases} P_{c1} - \dfrac{(P_{c1} - P_{c2})(f' - f_{avg})}{f_{max} - f_{avg}} & f' \geq f_{avg} \\ P_{c1} & f' < f_{avg} \end{cases} \tag{5}$$

$$P_m = \begin{cases} P_{m1} - \dfrac{(P_{m1} - P_{m2})(f_{max} - f)}{f_{max} - f_{avg}} & f \geq f_{avg} \\ P_{m1} & f < f_{avg} \end{cases} \tag{6}$$

Some parameters in the expression：

- fmax — max adapt value in race cluster
- favg — average adapt value in a general of race cluster
- f '— the bigger adapt value of crossed two individuals
- f — the adapt value of the individual to be mutated

The detail operation of AGA is listed below：

- Step 1, designate a concrete space area to solve the conflict and to be extricated.
- Step 2, create some air routes randomly according to the rules of AGA in the space area.
- Step 3, use the aim function and restricted condition to evaluate every air route which newly created. The purpose of using aim function is to make sure to keep the least windage between the new route and the original route. The function of the restricted condition is to make sure each new route has a safe alternation to the any other one.
- Step 4, take the actions of selection, crossing and mutating. Repeat step 3 and 4 until we have get the usable result data, at this time we can use the result data to solve the current fly conflict.

The aim function is expressed in below. The n is the number of aircrafts in the sector. The Si is the difference between the real distance of route in extrication area and the distance of original route.

$$y = \min \sum_{i=1}^{n} s_i \tag{7}$$

The restricted condition is the least distance between the aircraft Ai and Aj. It is expressed as rij > 0 . The NATMSS will exam if has the fly conflict between the flight path produced by AGA and other aircraft. If the conflict is existed that we set the adapt value equal to 0 to the chromosome of the individual gene, otherwise, for each aircraft i to calculate the difference named di between the real distance of route and the distance of original route. At last we can determine the value by using the expression below.

$$f = e^{-\frac{\sum_{i=1}^{n} d_i^2}{k}} \tag{8}$$

Constant k must be set compatibly to keep the high efficiency of the exponent function in the expression. We hope the point on the new route at where the conflict is solved should be more closer to the original rout, so we has add a punish function f to the adapt value which is created just now. Expression f is showed below, parameter d is the summation of all the distance of the extrication point to the out point of the original rout for n numbers aircrafts.

$$f = \begin{cases} f - 0.05, & 0 < d' < 10 \\ f - 0.10, & 10 < d' < 20 \\ f - 0.20, & d' > 20 \end{cases} \tag{9}$$

Next figure is the sketch map of conflict extrication

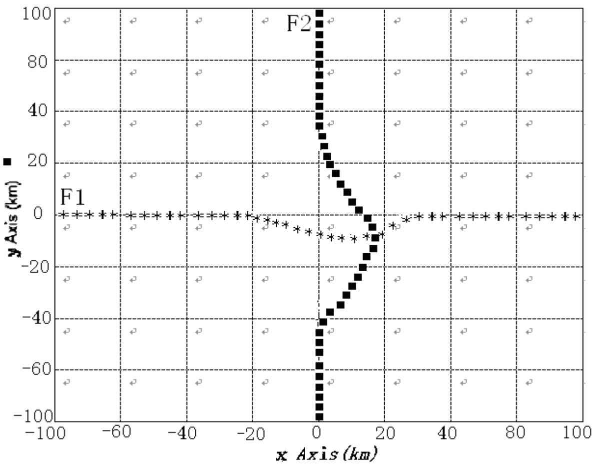

Figure 3. conflict extrication map

4.Scheduled flight sort algorithm based on genetic algorithm

The most airports in our country are modern with multi- runways currently, so how to arrange the take-off and landing on the multi-runways for aircrafts perfectly is a typical problem of a nonlinear, optimized and combined. It is suitable to be solved by genetic algorithm.

4.1.Design of individual gene and race cluster

Supposing that there are n numbers of scheduled flights flying on an airport with m numbers of runways, sequence Ai(i=1,2,…,n) delegate the scheduled flights that have known the information such as flight-type, take-off and landing time, total passenger number etc. If define the chromosome named A[k] (k=l, 2, …, m) for sorting all the scheduled flights (A1, A2, … An) which has the take-off order of time sequence on the multi-runways 1 to m, the A[k] is a gene just at the position number k on the hereditary coordinate, also this gene is the flight Ai in the all scheduled flights, at last the gene is the only initial state which corresponds to the time state of a fight stepping into or out off. Now we can set the initial state by selecting the number of original chromosome equal m, then form a waiting sequence of take-off flights on one of multi-runways by means of scratching up. Finally, we form the all initial states of the whole throng named A[1], A[2], … A[m], and the other states of chromosome are created symmetrically from the scheduled flights sequence A1, A2, … An.

4.2.Adapt function of arrangement of scheduled flghts

The adapt function F working for arranging the scheduled flights is listed below. Parameter αi is rights-add factor and αi is always bigger than 0. Parameter m is the total of all adapt functions. Parameter Fi is each adapt sub-function.

$$\min F = \sum_{i=1}^{m} \alpha_i F_i\left(A_{[i]}\right) \tag{10}$$

4.3.Restricted conditions

Define the collection A={1，2，…，n} as the data set of the scheduled flights, Ain is the sub-collection of landing flights, Aout is the sub-collection of take-off flights, thus Ain⊊A and Aout⊊A. Define L is the length of runway, Vi-min(i=1，2，…，n) is minimum speed of flight i, Vi-max (i=1，2，…，n) is maximal speed of flight i, hi is the real arrived time of flight i, Ehi is the earliest arrived time of flight i, Lhi is the latest arrived time of flight i, Yij is a dualistic parameter denoting the time order of two flights i and j, if flight i arrived before flight j that Yij equal 1, otherwise equal 0. The restricted conditions is showed below:

$$Ehi \le hi \le Lhi \quad (i=1, 2, \ldots, n) \tag{11}$$

$$Ehi = L / Vi\text{-}max \quad (i=1, 2, \ldots, n) \tag{12}$$

$$Lhi = L / Vi\text{-}min \quad (i=1, 2, \ldots, n) \tag{13}$$

$$Yij = 1 \quad (i, j = 1, 2, \ldots, n; \ i > j) \tag{14}$$

$$Yij = \{0, 1\} \quad (i, j = 1, 2, \ldots, n; \ i \ne j) \tag{15}$$

4.4.Genetic arithmetic operators

- Select：Save or delete strategy, eliminate the sort gene has a low adaptability.
- Cross：Adopt the sequence cross of multiple points. Reverse all genes in the hereditary coordinate of the chromosome to create new chromosome generation.
- Aberrance：Adopt the shift operation of multiple points and converse action of single point in the whole space created by flight sorting chromosome. Converse action means set gene n to the position 1, and make followed genes 1, 2, … n-l move backward.

Tabel1 lists out the emulation result data from a airport which has 3 runways and manage 10 flight at one moment by using genetic algorithm.

TABLE I. EMULATION SORT RESULT BY USING GA

	Sort by time order				Sort by GA			
Flight Num	Run ways	Takeoff time	Delay (S)	Sum of delay (S)	Run ways	Takeoff Time	Delay (S)	Sum of delay (S)
Flight-1	0	10:01:08	0	0	0	10:01:08	0	0
Flight-2	2	10:03:42	110	110	1	10:03:12	80	80
Flight-3	1	10:05:12	0	110	2	10:04:23	0	80
Flight-4	0	10:06:05	0	110	0	10:05:45	0	80
Flight-5	2	10:08:33	40	150	1	10:07:29	20	100
Flight-6	1	10:10:56	28	178	2	10:09:17	15	115
Flight-7	2	10:12:24	56	234	1	10:11:38	45	160
Flight-8	0	10:13:19	0	234	0	10:12:58	0	160
Flight-9	1	10:14:28	22	256	2	10:13:35	30	190
Flight-10	0	10:16:45	10	266	1	10:15:48	10	200
Flight-11	2	10:17:05	0	266	0	10:16:56	0	200
Flight-12	0	10:19:28	0	266	1	10:18:28	15	215

5.Conclusion

Genetic algorithm can solve the fly conflict and airport terminal arrangement efficiently, and economize the air-oil by commanding the aircraft fly along the direct air line and the lowest waiting cost. Look at the engineering, Adopt the GA can get optimum emulation result just pass through a little iterative loop, and it will be the most available and effective tools to proofing the manage level in air traffic control.

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